

SHAPE MEMORY ALLOY HEAT ENGINES AND ENERGY HARVESTING SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/447,317; U.S. Provisional Application No. 61/447,315; U.S. Provisional Application No. 61/447,328; U.S. Provisional Application No. 61/447,321; U.S. Provisional Application No. 61/447,307; and U.S. Provisional Application No. 61/447,324; all filed Feb. 28, 2011. All of which are hereby incorporated by reference in their entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was made with U.S. Government support under ARPA-E Contract number DE-AR0000040, awarded by the Department of Energy. The U.S. Government may have certain rights in this invention.

TECHNICAL FIELD

[0003] The present invention generally relates to energy harvesting systems, and more specifically, to energy harvesting systems using shape-memory alloy heat engines.

BACKGROUND OF THE INVENTION

[0004] Thermal energy may be produced by industrial, assembly, and manufacturing processes. Automobiles, small equipment, and heavy equipment also produce thermal energy. Some of this thermal energy is waste heat, which is heat for which no useful application is found or planned, and is generally a waste by-product. Waste heat may be expelled to the atmosphere. The burning of transport fuels also contributes to waste heat.

SUMMARY OF THE INVENTION

[0005] A heat engine is provided. The heat engine includes a first rotatable pulley and a second rotatable pulley spaced from the first rotatable pulley. A shape memory alloy (SMA) element is disposed about a portion of the first rotatable pulley at a first radial distance and about a portion of the second rotatable pulley at a second radial distance. The first and second radial distances define an SMA pulley ratio.

[0006] The SMA element includes a first wire, a second wire parallel to the first wire, and a matrix joining the first wire and the second wire. The first wire and the second wire are in contact with the first rotatable pulley and the second rotatable pulley, but the matrix is not in contact with the first rotatable pulley and the second rotatable pulley.

[0007] A timing cable disposed about a portion of the first rotatable pulley at a third radial distance and about a portion of the second rotatable pulley at a fourth radial distance. The third and fourth radial distances defining a timing pulley ratio, which is different than the SMA pulley ratio.

[0008] The SMA element is configured to be placed in thermal communication with a hot region at a first temperature and with a cold region at a second temperature lower than the first temperature. The SMA element selectively changes crystallographic phase between martensite and austenite and thereby either contracts and expands in response to exposure to the first temperature and the second temperature. The SMA

element thereby converts a thermal energy gradient between the hot region and the cold region into mechanical energy.

[0009] The above features and advantages and other features and advantages of the present invention are readily apparent from the following detailed description of the best modes for carrying out the invention when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a schematic diagram of an energy harvesting system including a heat engine;

[0011] FIG. 2 is a schematic side view of the heat engine of FIG. 1;

[0012] FIG. 3 is a schematic side view of another heat engine usable with the energy harvesting system of FIG. 1;

[0013] FIG. 4 is a schematic graphical representation of a work diagram for a heat engine, such as those shown in either FIG. 2 or FIG. 3;

[0014] FIG. 5A is a schematic, fragmentary cross-sectional view of a shape memory alloy (SMA) working element form having parallel strands of thin-wire SMA;

[0015] FIG. 5B is a schematic, fragmentary cross-sectional view of another SMA working element form having parallel strands of SMA partially embedded within a matrix;

[0016] FIG. 5C is a schematic, fragmentary cross-sectional view of a composite SMA working element built from individual units similar to those shown in FIG. 5B;

[0017] FIG. 6A is a schematic, plan view of a spring-based SMA working element having a fiber core within the spring coil;

[0018] FIG. 6B is a schematic, plan view of another spring-based SMA working element having two springs and a fiber core within the spring coils;

[0019] FIG. 6C is a schematic, plan view of another spring-based SMA working element having interleaved springs with two fiber cores within the spring coils;

[0020] FIG. 7A is a schematic, side view of a braided SMA working element and an inset close-up view of the same;

[0021] FIG. 7B is a schematic, side view of a woven mesh SMA working element and an inset close-up view of the same;

[0022] FIG. 8A is a schematic, isometric view of another heat engine having a multi-planar loop;

[0023] FIG. 8B is a schematic, isometric view of another heat engine having a multi-planar loop with a three-dimensional guide;

[0024] FIG. 9 is a schematic, illustration or diagram of an energy harvesting system having three, cascaded heat engines, in which the cold side of one heat engine acts as the hot side of another;

[0025] FIG. 10 is a schematic, side view of an energy harvesting system having a longitudinal heat engine;

[0026] FIG. 11A is a schematic, isometric view of an energy harvesting system having a plurality of heat engines and configured to capture thermal energy from high-aspect-ratio heat sources, such as pipes;

[0027] FIG. 11B is a schematic, isometric view of another energy harvesting system having a plurality of heat engines and configured to capture thermal energy from high-aspect-ratio heat sources and counter-flowing cooling sinks;

[0028] FIG. 12 is a schematic, fragmentary cross-sectional view of a round, three-dimensional SMA working element for use in large-scale heat engines;